Chiropractic Research Journal
Volume 1 • Number 1 • Spring 1988
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DENTATE LIGAMENT — CORD DISTORTION HYPOTHESIS

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ABSTRACT

The mechanism of nerve irritation resulting from upper cervical misalignments has usually involved either the nerve compression hypothesis or the proprioceptive insult hypothesis. Because of the diameter of the canal and the space between the cord and the wall of the canal, compression of the cord at the upper cervical area would require much larger displacements than are encountered in typical patients.

The proprioceptive insult hypothesis does not adequately explain the sensory phenomena experienced by some upper cervical patients and is cumbersome to use in explaining the mechanism behind an upper cervical subluxation causing sciatica.

The Dentate Ligament — Cord Distortion Hypothesis offers a mechanism whereby the effects of misalignments of the upper cervical vertebrae, via the dentate ligaments, produce mechanical distortions of the spinal cord. The clinical significance of the hypothesis and its relationship to supine leg length comparison, low back pain, and trigeminal neuralgia is discussed.

***Key Words:** Subluxations, cervical, adjustment, dentate ligament, Grostic technique, neurological hypothesis.*

DENTATE LIGAMENT — CORD DISTORTION HYPOTHESIS

From the time of D. D. Palmer to the present, the neurological component of the subluxation, i.e., interference with nervous system function has been a central tenet of chiropractic.1-7 Throughout the history of chiropractic various models and mechanisms have been developed to explain how vertebral misalignments produce this interference. These models have ranged from direct mechanical irritation of the spinal nerve or nerve root in the intervertebral foramen to the reflex hypotheses, e.g., somato-visceral, somato-psychic, etc.8. While many of these hypotheses are credible and some are under investigation at this time, there are still several types of subluxations for which these explanations are inadequate.5,8 Nowhere is this more apparent than in the upper cervical spine.

In order to explain the upper cervical subluxation the proprioceptive insult hypothesis is usually cited. This hypothesis has been described in detail by Homewood and more recently by Spencer.5,9 This hypothesis states that the vertebral misalignment (or derangement) produces a hyperstimulation of proprioceptive nerve endings in and adjacent to the articulation. This hyperstimulation results in a barrage of proprioceptive signals into the spinal cord and, it is hypothesized, causes an overload of the integrating circuits of the spinal cord. This results in impairment of spinal cord function at the level of the insult resulting in increased muscle tone around the articulation with possible effects being felt in other areas of the nervous system.10,11

The proprioceptive insult hypothesis, plausible as it may be in explaining cord irritation generally, becomes complex when one tries to explain how an upper cervical subluxation can produce symptoms in the lower spine and extremities, e.g., low back pain and sciatica. This hypothesis also fails to explain several of the clinical phenomena associated with the reduction or correction of an upper cervical subluxation.

Chiropractors using exclusively upper cervical adjusting methods have observed sudden and dramatic improvement in some patients with severe low back pain and sciatica. It is not unusual for this to occur almost simultaneously with the adjustment. It is also not uncommon for the patient to experience sensations of warmth (or even occasionally sensations of mild electric shock — Lhermitte's Sign) in the lower extremity simultaneously with the adjustment. Normally these changes and sensations would be considered indicative of spinal cord involvement. While it may be possible to explain these symptoms using the proprioceptive insult hypothesis, I would like to present a relatively new hypothesis.12-16 which may offer a simpler explanation and provide a useful tool for the understanding of upper cervical subluxations.

The Dentate Ligament — Cord Distortion Hypothesis, utilizes the unique anatomy of the cervical spine to provide a model which explains how a misalignment of C-1 or C-2 can produce neurological insult directly via mechanical irritation of the spinal cord, and indirectly via vascular compromise of the cervical cord. This hypothesis states that misalignments of the upper cervical vertebrae, because of their unique attachment to the spinal cord by means of the dentate ligaments.17,18 can directly stress and deform the spinal cord (Figure 1). Subsequently, this stress on the cord, in addition to direct mechanical

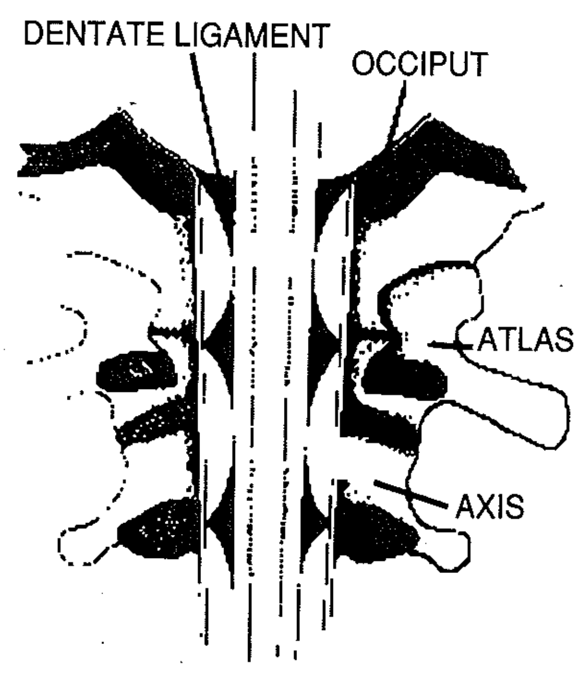

figure 1

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irritation, may produce venous occlusion with stasis of blood and resulting anoxia in particular areas of the upper cervical cord.19,20

This hypothesis combined with knowledge of the mechanics of the cervical spine may provide not only a simpler explanation of nervous system insult resulting from upper cervical misalignments but would appear to be clinically verifiable as well by predicting clinically observable phenomena associated with certain structural misalignments.

There are, however, three direct challenges to this hypothesis which must be answered before it can be accepted as viable:

- First -

IS THE DENTATE LIGAMENT MECHANICALLY LINKED TO THE OSSEOUS STRUCTURES OF THE UPPER CERVICAL SPINE?

- Second -

IS THE DENTATE LIGAMENT STRONG ENOUGH TO DEFORM THE SPINAL CORD?

- Third -

ARE THE OSSEOUS MISALIGNMENTS LARGE ENOUGH TO CAUSE MECHANICAL IRRITATION TO THE CORD?

CHALLENGE ONE

If misalignments of the cervical spine are to affect the spinal cord a mechanical linkage must exist between the osseous structures and the spinal cord. The anatomy of the upper cervical spine reveals several important facts. First, the dentate ligament is a fibrous band of piamater extending the entire length of the spinal cord on both sides. The lateral border of the dentate ligament presents a scalloped appearance because of toothlike projections which pierce the arachnoid mater and attach to the dura mater.17,18

The function of the dentate ligaments has been described by Cunningham's Anatomy as suspending the spinal medulla within the subarachnoid space, but the exact nature of this suspension has been debated in the literature. That the dentate ligaments are responsible for holding the cord in the anterior aspect of the canal, i.e., restricting anterior-posterior motion, as discussed in 1947 by Kahn and in 1954 by Schneider, now seems less certain.19,21 Stoltmann and Blackwood describe the dentate ligament's ability to transmit axial tensions from the cord to the dura, restricting movement in a cephalo-caudal direction.22

Further evidence that the dentate ligaments provide a unique function in the upper cervical region is provided by Key and Retzius who found that the strongest ligaments are the uppermost and that in the upper cervical region they are short, thick, and pass almost perpendicularly from the pia mater to their attachments on the dura mater.23 The size and

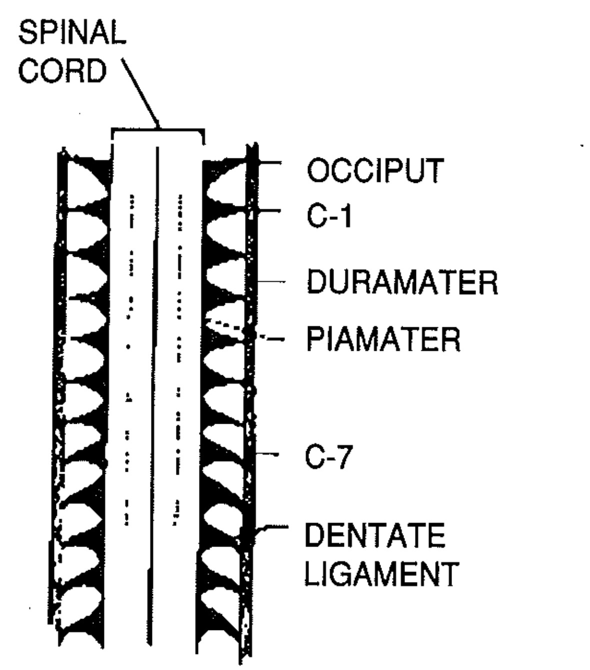

figure 2

strength of the ligaments indicate that they have a restraining function and their orientation is such that they would check vertical movement of the cord.

Between full extension and full flexion of the cervical spine there is a change in the length of the cervical canal of about 30 mm.24 This is accommodated by some longitudinal compression of the cord during extension and longitudinal stretching of the cord during flexion. Only in the upper cervical area are the dentate ligaments perpendicular to the cord (Figure 2). Based on these observations, it may be a primary role of the upper cervical dentate ligaments to restrict the downward-pulling axial forces created by the lengthening of the canal when the neck is flexed from being transmitted unattenuated to the brainstem.

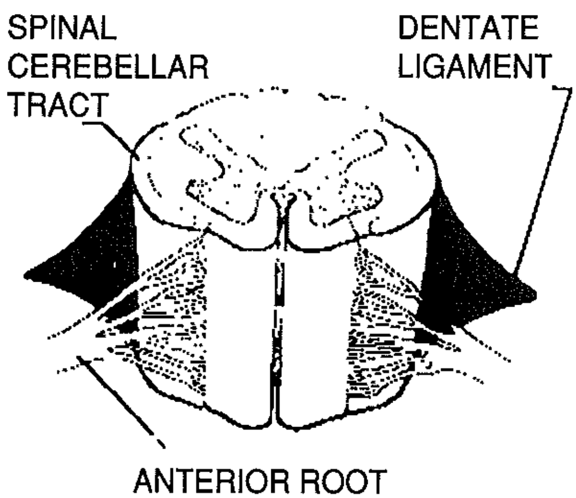

figure 3

If the cord were not anchored at the foramen magnum and in the upper cervical area via the dentate ligaments the axial forces produced by normal flexion of the cervical cord would be transmitted to the brainstem pulling downward on the brain. The ligaments thus appear to serve a protective role for the central nervous system during normal movement, but during abnormal movement of cervical vertebrae capable of transmitting pathologic forces to the spinal cord and brainstem.25

The spinal cord in the upper cervical spine is firmly attached to the dura mater by the dentate ligaments and the dentate ligaments are attached to the dura mater between nerve roots (Figure 3).18 There is general agreement that the dura is attached to the skull circumferentially at the foramen magnum, but whether the dura is attached to atlas is unclear in the literature. Gray's Anatomy states that the dura is attached to the foramen magnum, C-2, and C-3 while Cunningham's is silent on any attachment other than to the posterior longitudinal ligament.17,18

In a study by Waagen, Lindgren, Miller and Grostic in which frozen transverse 3-5 mm sections were made of the upper cervical spine, numerous strong attachments of the dura mater to the lateral masses and to the posterior arch of atlas were observed (unpublished observation). Similar strong attachments of the dura to the lateral and posterior walls of the canal formed by C-2 were also observed. These attachments appeared to be regular and consistent over several cadavers and there was no evidence of "tenting" of the dura which would indicate adhesions.

CHALLENGE TWO

That the dentate ligament is strong enough to deform the cord is well documented by studies done on the role of the dentate ligament.23,26 Brieg demonstrated that when the cord is stretched in cervical flexion instead of the expected decrease in diameter of the cord, the cord while attempting to reduce its diameter in both the sagital and coronal planes is restricted from constricting in the coronal plane by the dentate ligaments. The spinal cord is narrowed only in the anterior-posterior direction during cervical flexion because of the laterally located attachments of the dentate ligaments.27 Thus even in normal flexion the dentate ligaments are strong enough to slightly deform the cord.

While it would appear that the dentate ligament has been shown to slightly deform the cord during normal movement of the upper cervical spine, abnormal movement and misalignments of the upper cervical structures and their resulting effects on the spinal cord via the dentate ligament have yet to be discussed in the literature.

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Volume 1 • Number 1 • Spring 1988
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CHALLENGE THREE

Little has been published on the magnitudes of upper cervical misalignments. Bunton described two cases of lateral subluxation of atlas with respect to C-2.28 In both cases he noted lateral scoliosis of the cervical spine with a reverse tilt of the head back to the midline. While he noted that the articular surface of atlas overlapped the articular surface of axis on one side, the actual size of the misalignment is not discussed.

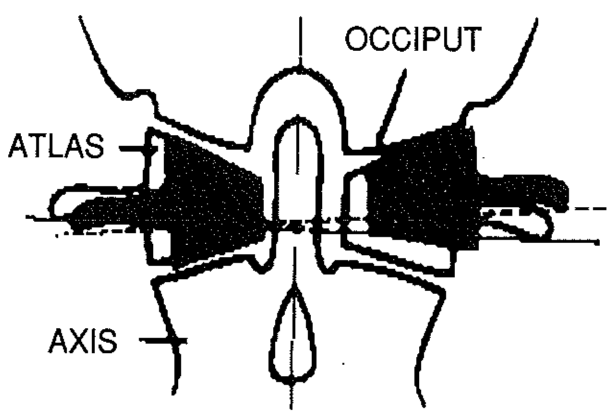

figure 4

In 1946, J. F. Grostic presented a means of measuring misalignments in the upper cervical spine.29 His system measured both lateral and rotational displacements of the atlas with respect to the skull as well as lateral and rotational displacements of the atlas with respect to the axis.15,29 Since that time numerous chiropractic procedures have used the method either in its entirety 30,31 or in modified forms.32-34 This method utilizes angular measurement to determine the magnitude of vertebral misalignments (Figure 4) because angular measurement is less sensitive to magnification distortion on the x-ray films than some direct displacement measuring systems. Direct displacements can be calculated, however, if one knows the radii of curvatures of the condyle and axial arcs (Figure 4) and applies the following equation:

Equation 1

Displacement = 2 •Radius •PI •Angular Displacement / 360.

Data from a retrospective study of 523 patients,36 all of whom had clinical signs of upper cervical subluxations, suggests that the average lateral misalignment between atlas and skull is 3 degrees and the average radius of curvature of the condylar arc is 57.2 mm. From equation 1, the average movement along the condylar surface was 3.0 mm. Because the superior articular surfaces of C-2 are usually flatter (larger radius of curvature) the lateral displacements of C-1 on C-2 can be even greater than the misalignments of C-1 with respect to the skull. With even moderate angular misalignments of C-1 on C-2 it is common for the inferior articular surface of C-1 to overlap the superior articular surface of C-2 (Figure 4).

The calculations above give the actual distance of the movement over the curved surfaces. Under certain circumstances the actual lateral displacement can be very closely approximated by using equation 1. As long as the misalignment angle is less than 10 degrees, the actual lateral deviation and the calculated arc deviation are in close agreement (at 3 degrees the error is less than 0.01 mm.).

With the transverse diameter of the spinal cord at the level of C-1 being about 13 mm, even an average lateral misalignment of 3 degrees producing a lateral displacement of 3 mm would deform the cord by greater than 23% of its diameter if its effects could be transmitted to the spinal cord unattenuated. It is probable that the elasticity of the dentate ligaments dissipates some of this stress, but, as Kahn discussed 19, chronic tension on a ligament may produce thickening and strengthening of the ligament, decreasing the ligament's ability to damp the distortive forces before they can deform the cord.

J. F. Grostic taught and other chiropractors using Grostic Procedure have since observed that, as a rule, the patient must have a misalignment of 0.75 degrees before neurologic manifestations are noted, i.e., positive supine leg length test (difference in leg lengths of greater than 8 mm).36 Not all patients begin to show symptoms of neurologic involvement at 0.75 degrees, but from clinical experience this does seem to be about the minimal lateral misalignment to do so. An angular misalignment of this magnitude would produce a lateral movement of almost 0.75 mm. While 0.75 mm may seem so small as to be within the nervous system's ability to adapt, it is interesting to note a study by Jirout in which he measured the maximum anterior-posterior movement of the spinal cord in the sagital plane at the level of the atlas and found it to be about 4 mm.37

Using this maximum distance and the approximate measurements of the atlas as published by Lang 38 it is possible to calculate that the lateral deviation of the cord produced by this motion's shortening effects on the dentate ligament is approximately 0.5mm. It seems that even at the limits of normal motion the distortion of the cord does not equal that of even the smallest clinically significant misalignment. Traction on the cord by misalignments thus would seem to be significantly larger than those produced by normal movement.

VASCULAR EFFECTS OF MISALIGNMENT

In addition to direct mechanical irritation of the tracts of the spinal cord, this mechanism may involve a vascular component.20 Gillilan, in an investigation of the venous drainage system of the cervical spinal cord, observed that the small radicular veins of the upper cervical cord were not as redundant as those elsewhere in the spinal cord and that mechanical obstruction of these veins could cause stasis of blood and ischemia in the portion of the spinal cord drained by these veins. She noted that venous stasis would tend to cause ischemia first in the lateral columns of the cord. Gillilan pointed out that because these veins operate at such low pressures, they are easily occluded by compressive forces. She further noted that the dentate ligament may be one means of transmitting mechanical stresses to the cord.

Important to this proposed model is that ischemia first increases the irritability of nerves.39,40 Thus, a purely mechanical irritation of the nerve tracts may be aggravated by localized ischemia and increased sensitivity to the effects of mechanical irritation.

CLINICAL SIGNIFICANCE

This new hypothesis of neurologic interference may help explain many of the neurological phenomena encountered in clinical chiropractic practice. In light of the Dentate Ligament — Cord Distortion Hypothesis, the structures and tracts of the upper cervical cord take on a much greater clinical significance for the chiropractor.

SUPINE LEG LENGTH TEST (GROSTIC LEG CHECK)

A cross section of the cord at the level of C-1 shows the relationship of the tracts of the cord to the points of attachment of the dentate ligaments (Figure 5). Brieg, using araldite (a transparent plastic) showed parabolic iso-force lines were created when compressive forces were applied. While his model was not quantitative, it did provide insight into the way forces resulting from compression may be transmitted within the cord.41 One would expect that while the force transmission within the cord resulting from tension would be different than that resulting from compression the iso-force lines would still be in similar patterns and traction on the cord by displaced dentate ligaments would approximate this pattern.

Force distribution alone, however, is not enough to predict where nerve irritation will occur. All tracts do not respond equally to equal mechanical irritation.42 Tracts with nerves fibers of larger diameter are more sensitive to mechanical irritation,43 than smaller diameter fibers, e.g., pain fibers.

The spinocerebellar tracts are composed of the largest axons in the spinal cord (type A fibers). They are located at the site of maximal mechanical irritation. If traction disrupts cord function it does so first in the spinocerebellar tracts, tracts responsible for muscle tone, joint position sense 44, and the status of interneuronal activity signaling the "internal state" of lower motor centers.45 The most lateral fibers innervate the most caudal structures.46 In the dorsal spinocerebellar tract the most lateral fibers innervate the lower lumbar and sacral area and are acted on

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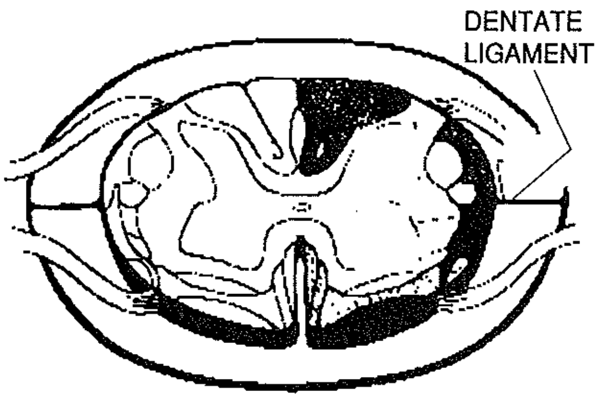

CS - CORTICOSPINAL TRACT
DSC - DORSOPINOCEREBELLAR
ST - SPINOTHALAMIC TRACT
VSC - VENTROSPINOCEREBELLAR

figure 5

monosynaptically by afferents of muscle spindles and tendon organs45. The ventral tract's lateral-most fibers may carry information about activity in segmental reflex arcs, segmental paths, e.g., muscle spindle and tendon organ afferents, and Renshaw cells.47 Involvement of either tract may affect the muscles of the pelvic girdle or the muscles of the lower extremities. It is hypothesized that spinal cord irritation caused by the dentate ligament traction may affect the muscles of the pelvic girdle and lower extremities producing hypertonicity and even spasticity of the involved muscles.

This increased muscle tone in the large muscles of the pelvis and thigh may cause the pelvic distortions manifesting as a functional short leg. In chiropractic there have been numerous attempts to directly measure pelvic distortion. Most recently Gregory developed an instrument to measure the various pelvic distortions that manifest as a short leg.48 That one of the first tracts of the spinal cord to be influenced by dentate ligament irritation is the spinocerebellar seems consistent both with the anatomical knowledge of the upper cervical spine and with the clinical use of the supine leg length test (Grostic Leg Check) as an indicator of neurologic interference from an upper cervical misalignment.

LOW BACK PAIN RELATED TO UPPER CERVICAL SUBLUXATION

The cross section of the cord (Figure 5) shows the that the spinothalamic tract lies close to the dentate ligament attachment points. Like the spinocerebellar tracts, the spinothalamic tracts are organized in laminar fashion with the most lateral fibers corresponding to the sacral and lower lumbar nerve distributions but carrying pain and temperature sensations.49

Mechanical irritation of the spinothalamic tract in the upper cervical cord caused by traction of the dentate ligament could produce pain in the low back and legs. This may explain some low back pain and sciatica, especially that which occurs in the absence of demonstrable local cause and is relieved almost instantaneously by an upper cervical adjustment. It may also explain the sensation of warmth or mild electric shock experienced in the legs or low back by some patients as they are adjusted in the upper cervical region.

TRIGEMINAL NEURALGIA AND UPPER CERVICAL SUBLUXATIONS

The Dentate Ligament-Cord Distortion Hypothesis may provide an explanation for the efficacy of correction of upper cervical subluxations in relieving trigeminal neuralgia. The paroxysmal nature of the pain indicates that it arises as a sudden discharge of neurons as a result of irritation of the trigeminal nerve or it could occur in the gasserian ganglion or in the spinal nucleus of the trigeminal nerve.50,51 The spinal nucleus of the trigeminal nerve may extend downward as far as the 4th cervical vertebra.51,52 By combining anterior rotation of the atlas on the side to which the atlas has laterally deviated with the lateral traction it may be possible to put traction directly on the sensory nucleus of the trigeminal nerve at the level of the first and second cervical vertebrae.

I have cared for a patient with severe trigeminal neuralgia in which rotational misalignment of the atlas appeared to be the most critical factor and required the greatest reduction before relief from the attacks occurred. Direct mechanical-vascular irritation of the spinal nucleus might also explain those cases in which surgical destruction of the ganglion or sectioning of the nerve fails to provide relief.53,54

Many additional studies on the effects of upper cervical misalignments on the central nervous system are needed before any firm conclusions can be drawn. Perhaps this hypothesized mechanism may encourage further, much-needed investigation into this important area. While the concept of encroachment of a foramen has explained direct irritation of the spinal nerve or nerve root and has been a basis of chiropractic care for many years, the dentate ligament mechanism may now describe a mechanism by which misalignments in the upper cervical spine can produce direct irritation of the spinal cord. Diagnostic procedures such as magnetic resonance imaging, whereby the spinal cord can be visualized, and studies using 3-dimensional dynamic models of the spine, resembling those of C. H. Suh, whereby dynamic stresses on the cord itself can be analyzed may lead to a greater understanding of the upper cervical subluxation and better procedures to reduce or correct it.55

ACKNOWLEDGEMENTS:

I thank Mr. Tom Strine who did the artwork for all of the figures. Thanks also to Drs. Janice Lindgren and Paul Miller for their work in disection.

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